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By

THE OHIO STATE UNIVERSITY
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To DEPARTMENT OF THE AIR FORCE
Air Force Office of Scientific Research
Bolling Air Force Base, D.C. 20332

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On FLUID DYNAMICS OF MULTIPLE NOZZLE ARRAYS

For the period June 1, 1980 - May 31, 1981

Submitted by Stuart L. Petrie
Department of Aeronautical and Astronautical
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INTRODUCTION

Comprehensive experimental and theoretical studies have been conducted at The Ohio State University to provide Characterization of mixing layers in supersonic flow fields. Particular emphasis has been placed on obtaining information on temperature turbulence. Measurements have been made with an electron beam in an arc-heated, supersonic wind tunnel. A number of papers, Petrie, (Refs. 1-5), Komar and Petrie (Ref. 6), Komar (Ref. 7), Gasperas (Ref. 8), Gasperas and Petrie (Ref. 9) and others have resulted from these studies.

In these studies, assessments of the relative influences of parameters such as turbulent scale and intensity, energy spectrum and density fluctuations on the mixing layer structure were made. A versatile experimental facility was assembled and experimental techniques were developed to measure the steady state and certain of the time-resolved gasdynamic flow properties. Supporting theoretical analyses were also conducted which allow variation of the turbulence model employed to characterize the mixing within the shear layer. The more salient aspects of both the theoretical and experimental studies are summarized below.

EXPERIMENTAL STUDIES

The experimental studies on mixing layers have been conducted in a continuous flow, direct current, arc-heated wind tunnel facility. Two overall nozzle configurations were available. In

the baseline configuration both nozzles were supplied from the arc-heated reservoir. In the two-stream system, one nozzle was supplied by the arc-heated reservoir while the other was separately supplied with an arbitrary unheated gas. The latter configuration was designed to allow study of large velocity, temperature and density differences.

Both contoured and wedge nozzle blocks were available for both configurations. In addition, the center nozzle element was designed for ease of replacement to allow a variety of mixing layer injection schemes to be investigated. The nozzle block holder permitted rapid alteration of the nozzle array configuration for different Mach numbers or internal injection methods. Operating with either air or molecular nitrogen, typical reservoir pressures and temperatures were 1.0 atmosphere and 2000 degrees Kelvin, respectively.

An electron beam provided the primary instrumentation system for analysis of the mixing region. In this technique, a narrow beam of electrons was projected across the flow in a direction perpendicular to the gas velocity. Profiles of the gas properties were obtained by examining various points along the length of the electron beam and measurements were made at various stations downstream of the nozzle exit.

In conventional application of an electron beam, only the steady state gas properties are measured. However, during the course of the studies, theoretical and experimental analyses were conducted to allow isolation of the rotational temperature

turbulence, independent of fluctuations in other gas properties and electron beam operating parameters. This technique allowed direct measurement of the temperature turbulence at arbitrary locations within the flow field and yielded data which could be used to judge the applicability of various turbulence and mixing models. In addition to the electron beam, conventional pitot pressure and mass flow probes were also used to examine the mixing region.

THEORETICAL STUDIES

Particular emphasis was placed on the development of a versatile numerical model for turbulent mixing of co-planar flows. The resulting computer program is capable of calculating turbulent two-dimensional compressible boundary layer flows along a body and in wakes and free shear layers. Heat transfer to the nozzle wall is included in the analysis and appears to be particularly important for nozzle flows where the boundary layer is subject to very high heat transfer rates in the region near the nozzle throat. Additionally mass diffusion of a binary mixture is permitted in the shear layer subject to the assumption of unity Lewis number.

Closure of the system of equations can be accomplished with a number of models. These include:

1. the Cebeci-Smith model
2. a Glushko single transport equation model
3. the two-equation model
4. the Donaldson transport equation model

Since the static temperature fluctuation was the principal quantity measured in the experimental studies, significant effort was devoted to obtaining accurate predictions of the temperature turbulence.

SUMMARY OF RECENT WORK

During the past year of the Grant, the experimental studies with the baseline nozzle configuration were completed. Detailed scans of the shear layer at three locations downstream of the nozzle exit were conducted to obtain both the steady state and fluctuating rotational temperatures.

The theoretical analyses of the shear layer flow were also completed during the past year. Detailed numerical experiments with the computer code were conducted to provide comparisons with the experimental results. In general, the steady state data compared well with the theoretical results. However, the comparisons between the theoretical and experimental turbulence results were poor.

Complete comparisons of the theoretical and experimental results are contained in Ref. 8

The research conducted to date fills an important gap in the information available for free shear layer flows, since it deals with the supersonic case. However, additional experiments are clearly needed and other fundamental fluid quantities should be measured. For example, one level of modelling can be eliminated by comparing turbulence levels for velocity rather than temperature. In addition, Reynolds stress measurements would be

extremely helpful in understanding the structure of the shear layer. Such measurements can be made with a laser Doppler velocimeter.

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